3. Ground Water & Hydrology

Needs to Know Criteria
▪ Relationship of the hydrologic cycle to site operation and function
▪ Evapotranspiration
▪ Wastewater runoff
▪ Impacts from runoff
▪ Surface ponding
▪ Effects of ponding on ground water
▪ Eutrophication
▪ Saturated zone, unsaturated zone, water table, ground water, surface water, and ground water interconnection
▪ Depth to ground water
▪ Effects of ground water level fluctuations during the growing season or non-growing season
▪ Locating ground water monitoring wells
▪ Impacts of improperly operated land application systems
▪ Wastewater mounding
▪ Obtaining background or baseline ground water samples prior to wastewater land application
▪ Construction requirements and routine maintenance for ground water monitoring wells

To determine if a wastewater land application treatment system is functioning properly, an operator needs a basic understanding of ground water and hydrology. *Hydrology* is simply the study of water as it occurs on and below the surface of the earth as well as in the atmosphere. The movement of water on the land, in the ground, and through the air is termed the *hydrologic cycle.*

3.1 The Hydrologic Cycle

Needs To Know!

The hydrologic cycle is the continuous process of water leaving the earth's surface and eventually returning in the form of precipitation (Figure 3-1). Water falling from the atmosphere as rain or snow can do one of three things:

- evaporate and return to the atmosphere
- run off to streams, rivers, lakes and oceans
- infiltrate into the soil

Land-applied wastewater acts in much the same way as natural precipitation and becomes a part of the hydrologic cycle. In a properly operated land application system, however, wastewater should either evaporate or infiltrate into the soil.

Runoff of wastewater from land application is not acceptable. Percolation of untreated or partially treated wastewater below the root zone is also undesirable. Therefore, one of the most important goals for a land application system operator is to apply wastewater at rates that will not only supply the nutrient needs of crops or vegetative covers, but that will not exceed the rate at which the soil/crop system will accept and hold wastewater.

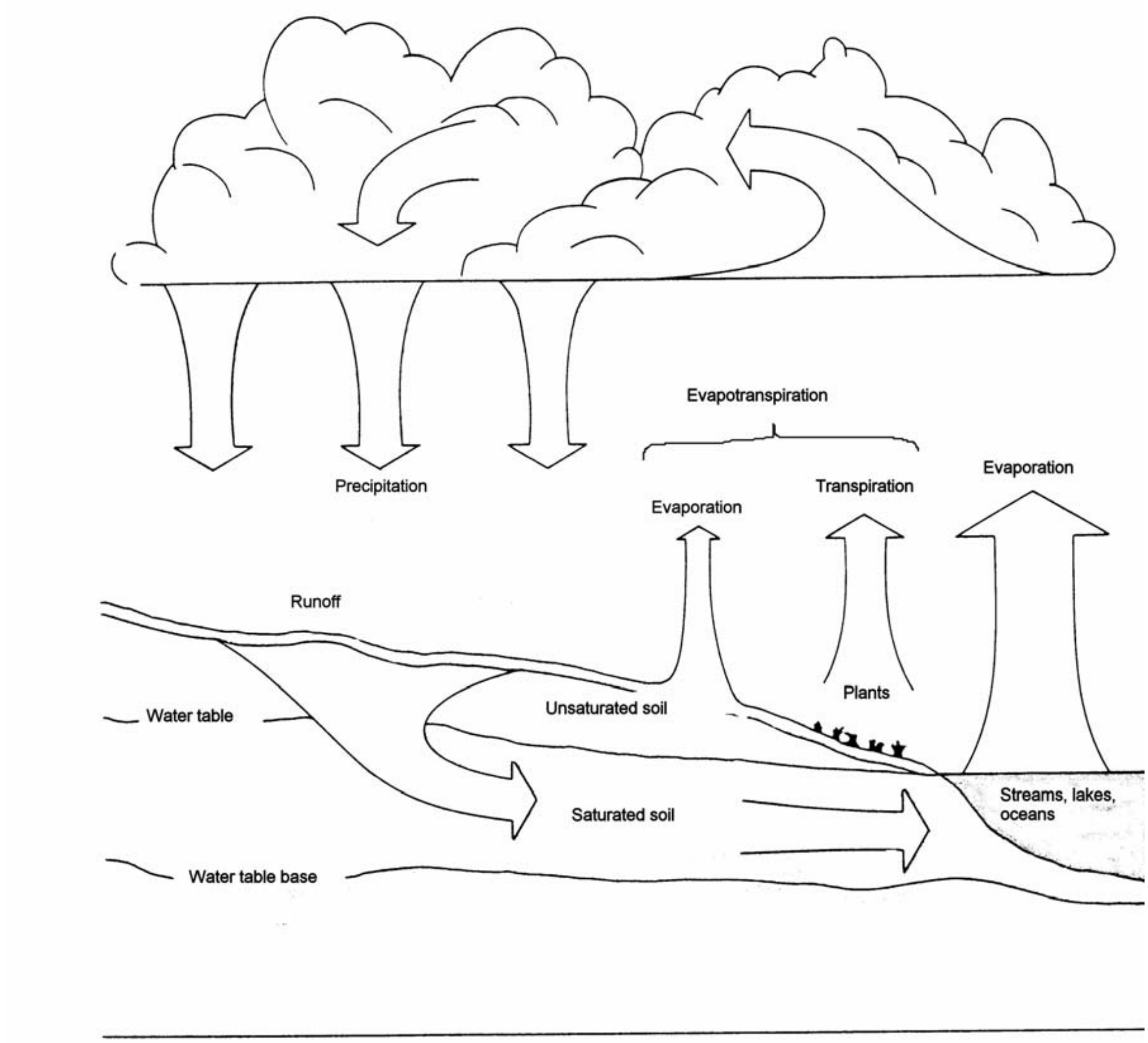


Figure 3-1. The hydrologic cycle (Brady 1990).

3.2 Evaporation and Evapotranspiration

Precipitation and wastewater can evaporate in several ways. When the humidity is low, water may evaporate before it even reaches the ground. More importantly, for the purposes of land application, water can also evaporate from the soil surface and from leaf surfaces.

The evaporation at leaf surfaces of water moving upward and through a plant is called *transpiration*. The combined loss of water to the atmosphere by evaporation from the soil surface (E) and by transpiration (T) is called *evapotranspiration* (ET) (Figure 3-2).

Evapotranspiration is responsible for most of the water removal from soils during a crop's growing season. Evapotranspiration rates are influenced by the following factors:

- *sunlight*: solar radiation provides the energy necessary for evaporation to take place; ET is higher on a bright sunny day than on a cloudy day.

- *atmospheric vapor pressure*: evaporation occurs when the atmospheric vapor pressure is low compared to the vapor pressure at the soil and leaf surfaces; ET is higher in arid climates than in humid regions.
- *temperature*: a change in temperature has a much greater effect on the vapor pressure at soil and leaf surface than on the atmospheric vapor pressure; ET increases with an increase in temperature.
- *wind*: the movement of air sweeps away vapor moisture from wet surfaces; high winds will intensify ET.
- *soil moisture content*: water must be present for evaporation to occur; ET is higher from moist soils compared with soils with a low moisture content.

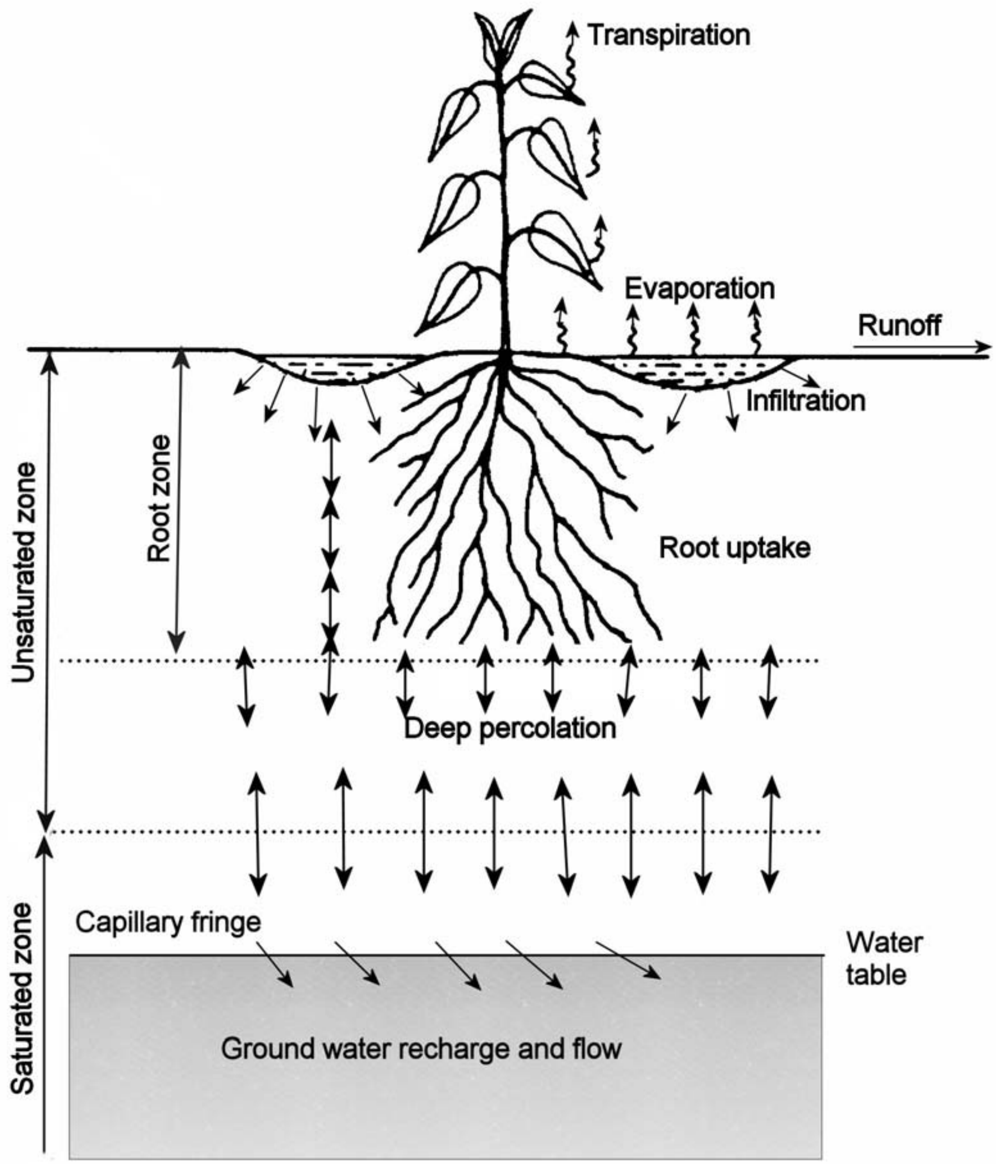


Figure 3-2. The water balance of a root zone (Hillel 1980).

After evapotranspiration occurs, water vapor in the atmosphere condenses into clouds. Eventually precipitation falls in the form of rain or snow and the cycle begins again.

3.3 Runoff to Surface Waters

Precipitation or wastewater that does not evaporate to the atmosphere or infiltrate into the soil is called *runoff*. Runoff travels over the soil surface, with the potential of eventually reaching *surface waters* (streams, rivers, lakes, and oceans). Factors affecting runoff are the same as those affecting infiltration (see Section 2):

- soil texture
- soil structure
- soil moisture
- vegetative cover
- topography and landscape position

Runoff from precipitation or land applied wastewater can negatively impact both soil and water quality. These negative impacts include soil erosion and surface water pollution. Runoff may also collect in low spots at a land application site to create areas of ponding.

Soil Erosion

When runoff occurs due to excessive precipitation or improper application of wastewater, runoff carries with it suspended soil particles. This loss or movement of soil is called *soil erosion.* Around five billion metric tons of soil are moved annually in the United States, some two thirds being moved by water (the remainder being moved by wind).

Unfortunately, much of this eroded soil ends up in surface waters. Sediment carried by runoff clogs streams, fills lakes, and often carries nutrients and pollutants to these waters. The lifetime of water storage reservoirs can be significantly shortened, river channels can be filled in, and water treatment plants can be damaged by the addition of sediment.

Sedimentation causes *turbidity*, which can smother aquatic life and shade out desirable aquatic vegetation. Sediment also may carry pesticides—such as herbicides and insecticides—that may be toxic to aquatic plants and animals. The varying chemical properties of pesticides—for example, their solubility, toxicity, and chemical breakdown rate—determine the potential damage to water quality.

Reducing soil erosion is the key to reducing the damaging effects of sedimentation. Fortunately, with current technology, erosion can be reduced to acceptable levels. The challenge is to match the appropriate technology to each situation.

Surface Water Pollution

In addition to soil particles, runoff can carry with it other waste constituents that affect water quality. Bacteria, viruses, organics, and a variety of other chemicals may impact plant and animal life in surface waters. These pollutants also have the potential to impact humans who use these surface waters for fishing, recreation, or drinking water supply.

Nutrients carried by runoff to surface waters can also result in accelerated *eutrophication*. Natural eutrophication is the slow nutrient enrichment of streams and lakes and is responsible for the "aging" of ponds, lakes, and reservoirs.

Rapid eutrophication is usually associated with increased algae growth or “blooms”. In freshwater ecosystems developed under very low phosphorus conditions, large additions of nutrients, especially phosphorus, can stimulate the production of these algae blooms. As the algae die, organisms in the aquatic system decompose the algae to use as a food source. In the process, they also use significant amounts of oxygen. As more and more algae grow and then decompose, dissolved oxygen levels are depleted in slow moving water. This condition can result in fish kills, offensive odors, unsightliness, and reduced attractiveness of the water for recreation and other public uses.

Ponding

If the topography of a land application site includes low-lying areas, runoff may collect in these areas and create *ponding*. Concerns with ponding include those associated with hydraulic overloading of a site. In addition, land application sites strive to prevent wastewater from ponding to the point where the ponded wastewater *putrifies* (decomposition of waste elements in the wastewater) or supports *vectors* (insects that may transmit disease-producing organisms).

3.4 Infiltration into the Soil

Factors important to soil infiltration include soil water, water table depths, artificial affects to site hydrology, and ground water monitoring wells; these are all discussed in the following.

Soil Water

Water that does not either evaporate or move as surface runoff infiltrates into the soil and percolates downward. As discussed earlier, some of this water is used by plants and is removed from the soil environment by evapotranspiration. The remaining water flows through the unsaturated portion of the soil (*unsaturated zone*) until it reaches the *saturated zone* (Figure 3-3). This is the zone in which all of the pores in the soil or bedrock are filled with water. The surface or uppermost level of the saturated zone is called the *water table*. When water percolating through the soil reaches the water table, it becomes *ground water*. Ground water is any water contained in interconnected pores located below the water table.

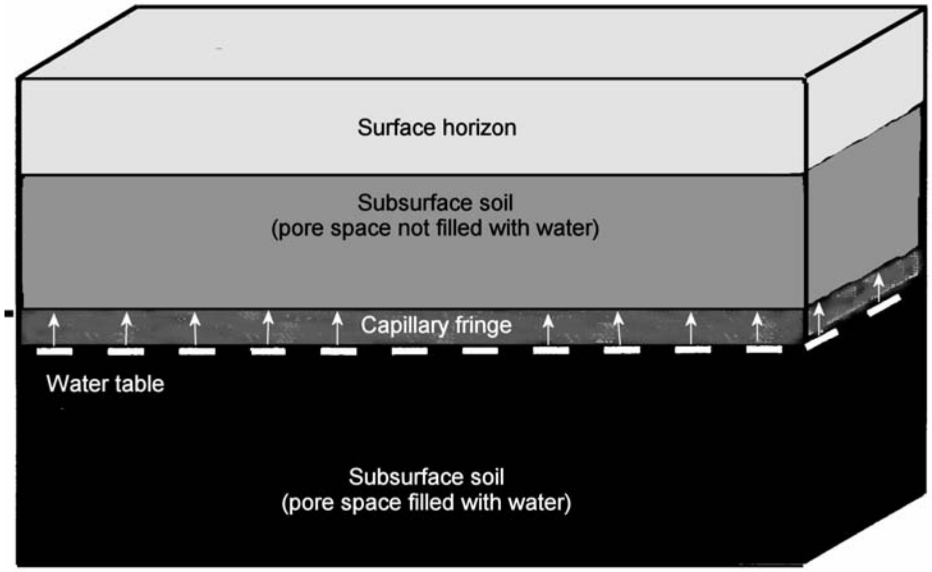


Figure 3-3. Divisions of soil water.

Although we often think of ground water occurring in large underground lakes or streams, it does not. Instead, it occupies spaces within rock fractures or between particles of sand, gravel, silt, or clay and flows through underground formations called *aquifers*. An aquifer is the rock or sediment in a formation, group of formations, or part of a formation that is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs.

Ground water does not move rapidly in an aquifer. It may move only a few feet per month or even per year, whereas surface streams flow several feet per second.

Although the unsaturated zone and the saturated zone appear to be distinct and separate areas, it is important to remember that they are part of a continuous flow system. It is sometimes difficult to determine exactly where one ends and the other begins.

Ground water often rises into the soil immediately above the water table by a process known as *capillary action* (the physical attraction of water to soil or rock particles). This area, where water from the saturated zone is pulled up into the unsaturated zone by capillary action, is called the *capillary fringe*.

The height of the capillary fringe is determined by the texture of the soil. In finely-textured soils, the capillary fringe may be several inches high; in coarsely-textured soils it may be insignificant. Although there is some debate about whether the capillary fringe is part of the unsaturated or the saturated zone, for the purposes of this manual we will consider the capillary fringe to be part of the saturated zone.

Water Table Depths

Water table depths vary across the landscape and are determined by the confining layers present below the soil surface. These confining layers have little to no permeability and, therefore, restrict water movement. These layers may be very deep and cover a large area, such as a bedrock layer.

A water table that results from a confining layer is called an *apparent* or *permanent* water table. Water table depths can be determined by measuring the depth to free water in a shallow, unlined auger hole.

A water table may also be caused by a shallow restrictive horizon in the soil that creates saturated conditions above it, while unsaturated conditions exist below it. This type of water table is called a *perched water table*, and usually occurs over a small area (Figure 3-4). Perched water table depths are quite variable and are usually of shorter duration than an apparent water table.

Water table depths also move up and down in response to precipitation and evapotranspiration patterns. The unsaturated zone can become saturated during periods of excessive precipitation. Saturated conditions in the unsaturated zone, however, are temporary and are usually seasonal (see Figure 3-5).

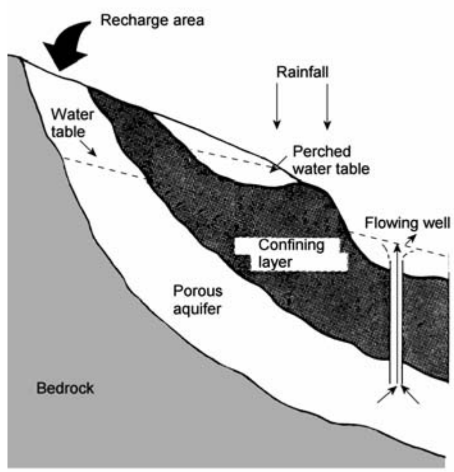


Figure 3-4. Porous aquifer and perched water table above an impermeable layer (Brooks et al 2003).

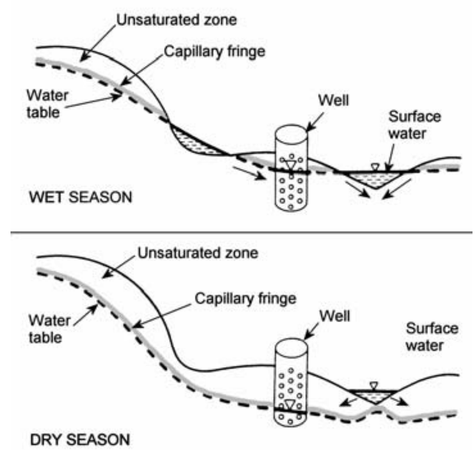


Figure 3-5. Ground water characteristics and water table changes from wet to dry season (Brooks et al 2003).

The goal of a land application system is to use the unsaturated zone of the soil, in conjunction with a suitable vegetative cover, to adequately treat wastewater before it reaches the saturated zone (i.e., ground water). These systems are designed to operate in aerobic environments. Therefore, depth to the water table is important because it determines both the volume of unsaturated soil through which waste constituents must travel before reaching ground water and the amount of time that waste constituents are in contact with unsaturated soil. The potential for ground water contamination increases where the soils are thin and the underlying bedrock or confining layer is permeable, or where the water table is near the soil surface. Such sites would not be considered suitable for land application systems. Generally, at least three (3) feet of unsaturated soil are needed for adequate waste treatment.

Even when the water table is sufficiently deep, the potential for ground water contamination exists. Over-application of wastewater can alter the hydrology of a site and create saturated conditions in what would normally be the unsaturated zone. Gravel and fractured bedrock—and improperly constructed monitoring wells—can create a direct conduit to ground water. Over application of fertlizers can result in leaching nitrates and other pollutants into the ground water.

The water table can rise closer to the soil surface, creating a situation called *ground water mounding*, which is defined as a localized rise in the water table, during wastewater land application, caused by a subsurface confining layer (Figure 3-6). This situation, if close enough to the soil surface, is undesirable: it can cause anaerobic conditions in the root zone and limit the growth potential of the vegetative cover, and it can also result in poor treatment of the wastewater. Insufficiently treated wastewater can pond on the soil surface, percolate to deeper ground water, or flow laterally as ground water until it reaches a surface water body (surface water and ground water interconnection).

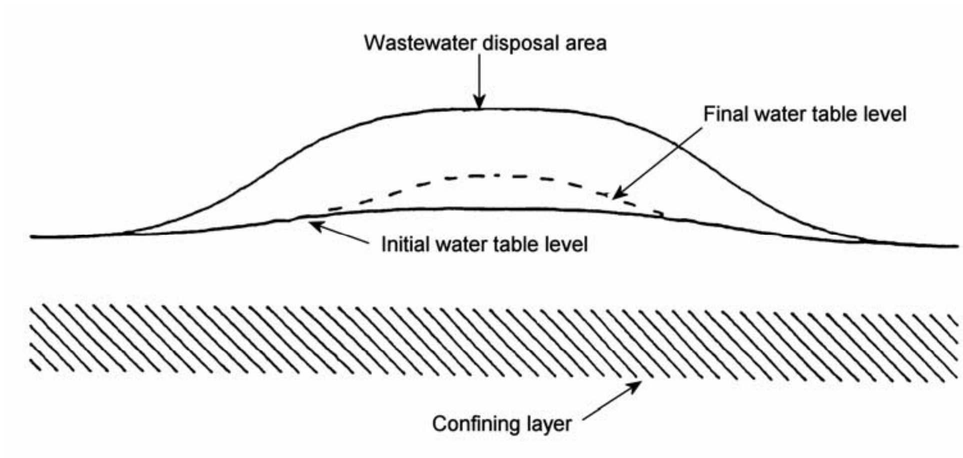


Figure 3-6. Ground water mounding under treatment system (North Carolina 1989).

Artificially Affecting Site Hydrology

Pumping water from a well can also alter the natural hydrology of a site. Although drinking water wells are recommended to be beyond 500 feet of the wetted area of a land application system, it is important to understand that pumping water from a well can change the natural flow of ground water in its vicinity. The net result can be a complete reversal of the natural direction of ground water flow. Thus, a downgradient contaminant may actually be drawn against the natural flow into an upgradient well. The possible range of such an effect depends on the rate of pumping and the ability of water to move within the aquifer.

Artificial surface and subsurface drainage can also affect ground water levels. Surface drainage is sometimes used where upslope runoff may impact a site. Surface water is diverted by means of dikes or berms that carry surface water runoff safely away from a treatment site. Installation of any surface drainage structures at a land application site would require approval by the DEQ regional office in your area.

Subsurface drainage is often used in agricultural settings. Ditches or porous pipes withdraw water from the soil and carry it to an off-site waterway, such as a road ditch or stream. However, installation of subsurface drainage at a land application site may be unacceptable and would require approval by the DEQ regional office in your area.

Ground Water Monitoring Wells

Many wastewater land application sites maintain a system of monitoring wells to assess how land application practices are impacting ground water. Ground water monitoring often plays a major role in evaluating and modifying management and loading practices to protect and maintain ground water quality. The location and the optimum number of monitoring wells depends on site specific characteristics, such as the number of land application fields, the size (acreage) of the fields, ground water flow characteristics, and the purpose of the monitoring system.

Well Location

The location of ground water monitoring wells is important to evaluate the change in ground water quality as it progresses through the wastewater land application site. Up-gradient monitoring wells indicate the existing ground water quality, and down-gradient wells indicate the effect the wastewater land application site has on ground water quality.

To achieve their intended purpose, monitoring wells must be located along the path of groundwater flowing underneath the wastewater land application site. Typically, at least one well is installed hydraulically *upgradient* and at least two wells are installed hydraulically *downgradient* of the wastewater land application site, as shown in Figure 3-7.

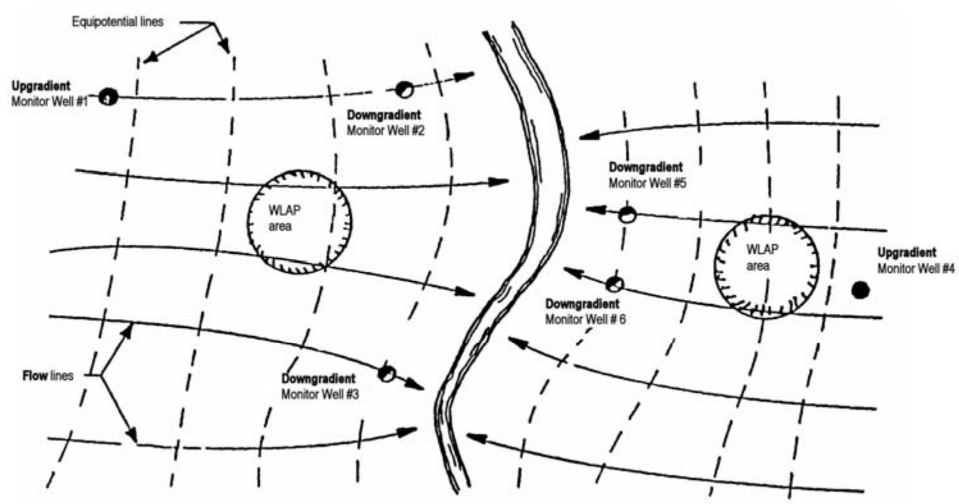


Figure 3-7. Proper and Improper Locations for Groundwater Monitoring Wells. (Wells #1, 2 and 3 are improperly located; wells # 4, 5 and 6 are properly located.)

Analyses of groundwater sampled from the upgradient well establishes the quality of groundwater unimpacted by the wastewater land application site (i.e., background quality), while groundwater samples from the downgradient well establish (by comparison with upgradient samples) the impact of wastewater land application operations on groundwater quality.

Well Construction

Along with proper location, proper well construction is critical to a valid and acceptable groundwater monitoring network. The construction requirements are presented in *Guidance for Land Application of Municipal and Industrial Wastewater*, pages 101-104, a copy of which is included in Appendix A. Some of the most important requirements include the following:

- The well casing and screen must be made of materials compatible with the constituents of the wastewater being monitored. Poly-vinyl chloride (PVC) is generally a good choice because of its ease of handling and low cost. However, the pieces of casing and screen must be joined using threaded couplings. Glues of any sort cannot be used, since volatile/semi-volatile elements in glues may leach into the groundwater.
- The length and positioning of the well screen below land surface must be such that the static water table is never above the uppermost or below the lowermost screen openings at any time of the year (Figure 3-8). Screen settings that do not meet this criteria result in either “dry” wells (i.e., the water table is below the screen, precluding collection of a sample) or a situation where the layer of dissolved contaminants in the groundwater may be above the zone where the sample is collected (i.e. the water table is above the uppermost screen openings).

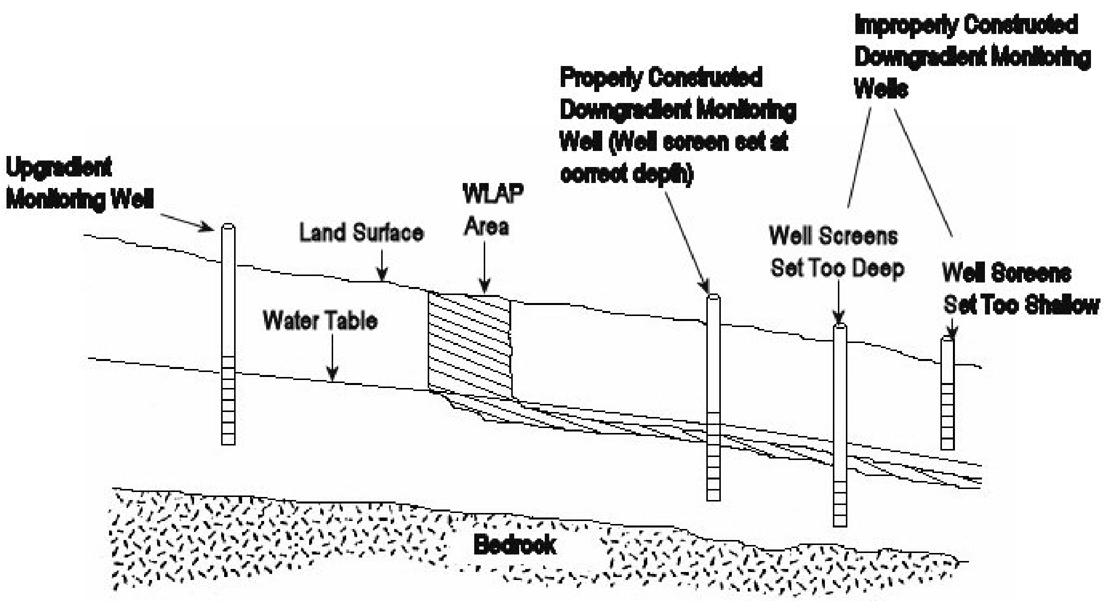
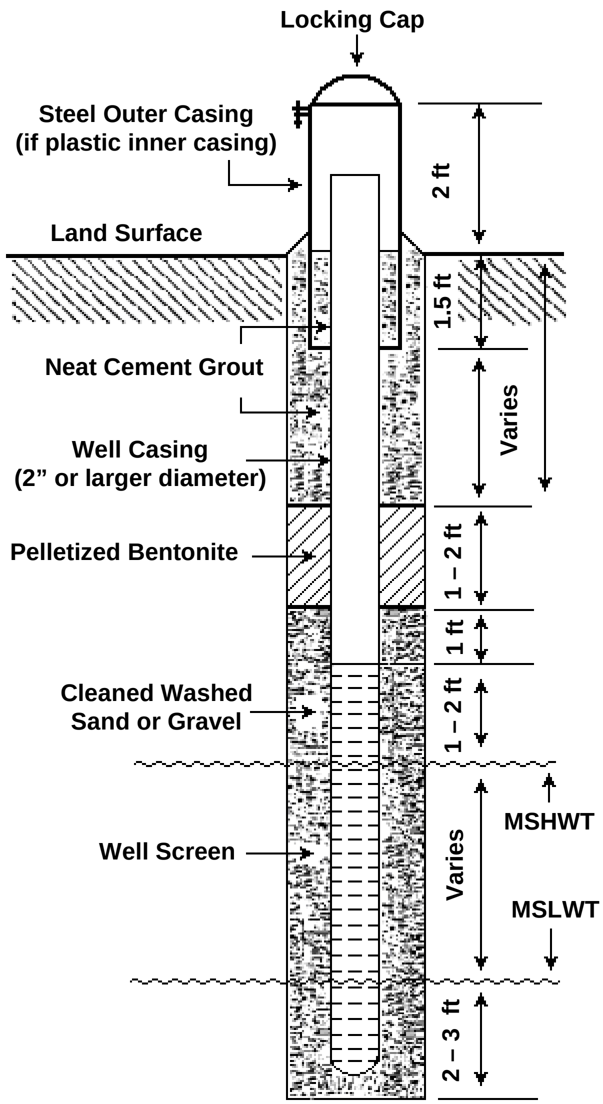


Figure 3-8. Proper and Improper Placement of Screens for Monitoring Wells.

- The well casing must be grouted from the land surface to a depth of no more than three feet above the top of the well screen. Because of shrinkage when dry, bentonite grouts may not be used, except as a plug to keep cement grout away from the well screen (Figure 3-9).



1. Borehole to be at least 4 inches larger than outside diameter of casing.

2. Casing and screen to be centered in borehole.

3. Top of well screen should extend from approx. 1 – 2 feet above MSHWT down to 2 – 3 feet below MSLWT.

4. Casing and screen material to be compatible with type of contaminant being monitored.

5. Well head to be labeled with visible warning saying: “Well for monitoring and not considered safe for drinking”.

6. Well to be afforded reasonable protection against damage after construction.

Note:

MSHWT = Mean Seasonal High Water Table

MSLWT = Mean Seasonal Low Water Table

Figure 3-9. Construction Details for Ground Water Monitoring Well.

- A permanent, easily visible label or tag must be attached to each well, denoting that the well is for monitoring and thus water from the well should not be used for drinking. There should also be a permanent label containing details about the construction of the well (date installed, installer, depth, etc.).

- The well must have a watertight lockable cap to prevent unauthorized access.

Baseline Well Characteristics

Because the purpose of installing monitoring wells is to determine the condition of groundwater based on the analyses of groundwater samples, it is essential that good quality samples be obtained. Prior to accepting a newly installed monitoring well, permittees should verify that the well has been properly developed. Suspended particles and sediment in groundwater samples, due to improper well development, interfere with some chemical analyses and can lead to compliance problems and additional financial outlays.

All wells should be sampled initially after construction, prior to wastewater land application activities, to establish a valid background concentration for constituents requiring routine monitoring. Thereafter, monitoring frequency will be determined by the schedule specified in the permit.

Reporting Requirements

Groundwater monitoring data must be reported in the annual and/or monthly or other frequency report(s). Be consistent in reporting well location and identification numbers, and designate each well as upgradient or downgradient in relation to the wastewater land application site. Identify wells using the serial numbers designated in the current permit.

3.5 Summary

In conclusion, the soil-plant system can effectively treat wastewater constituents and prevent them from reaching ground water if the system is properly sited, operated, and maintained. It is important to remember that soils vary tremendously in their treatment capacity. Under some conditions, waste constituents may take months or years to move from the soil surface to the ground water. Under other conditions, they can flow almost directly into the ground water. Once waste constituents reach the saturated zone, they are available for withdrawal from a drinking water well or discharge to adjacent surface waters, possibly jeopardizing both public health and environmental quality.

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